Program Objectives
1. Monitor annually for disturbance events inside and outside park boundaries such as fires, landslides, and urban development.
2. Monitor each decade for long-term changes to park landscapes caused by gradual impacts such as global climate change.
3. Use observations from the program to provide broader context for changes observed in the other Vital Signs monitoring programs.

Photo: Monitoring Landscape Dynamics records large-scale changes, like the Panther Creek fire in 2009, North Cascades National Park. NPS/Anderson

Landscape Dynamics

FROM THE 210 ACRES OF HISTORIC SETTLEMENTS AT Fort Vancouver National Historical Site to the 922,000 acres of wilderness at Olympic National Park, the parks of the North Coast and Cascades Network (NCCN) range tremendously in shape and size. Within these parks, NPS researchers study an array of natural resources selected as indicators of park health as part of the National Park Service's Vital Signs monitoring program. The majority of these studies focus on intensive monitoring of key natural resources: Changes in fish populations provide insight into the health of watersheds, shrinking glaciers serve as sensitive indicators of climate change, and changes in land bird populations are indicators of terrestrial ecosystem health. While these monitoring programs center on information about a specific resource, the landscape dynamics monitoring program instead addresses the "big picture." It spans the forests, rivers, and mountainous peaks found inside our parks as well as the public and private lands surrounding the parks. Its goal is to provide current information about major landscape changes that influence the other Vital Signs being monitored.

From year to year, any number of events can alter a landscape, such as landslides, floods, fires, clearcuts, and human development. Over longer periods of time, gradual changes such as warming from global climate change can lead to the accelerated melting of glaciers or a rise in tree mortality. These changes occur at any variety of temporal and special scales, from recurring small floods in a riparian zone to a single fire that burns thousands of acres. Each event can have lasting effects on the rest of the ecosystem. The NPS wants to know where these changes occur, how severe they are, and how long they last.

By: James Andrews

The landscape dynamics monitoring program uses satellite imagery (like the one below), Geographic Information Systems (GIS), and statistical analysis to evaluate the landscape's annual and decadal disturbance events in and around each park, tracking each event's size, duration, and intensity. Due to recent advancements in satellite imaging and remote sensing technology, researchers can now efficiently detect these changes over large areas and at a relatively low cost.

The landscape dynamics program was tested at Olympic, North Cascades, and Mount Rainier National Parks in the spring of 2011. Once fully implemented at all NCCN parks, the program will allow the NPS to monitor landscape changes indefinitely, gaining new insights into changes in frequency and severity of landscape-altering events in the Pacific Northwest as time progresses.
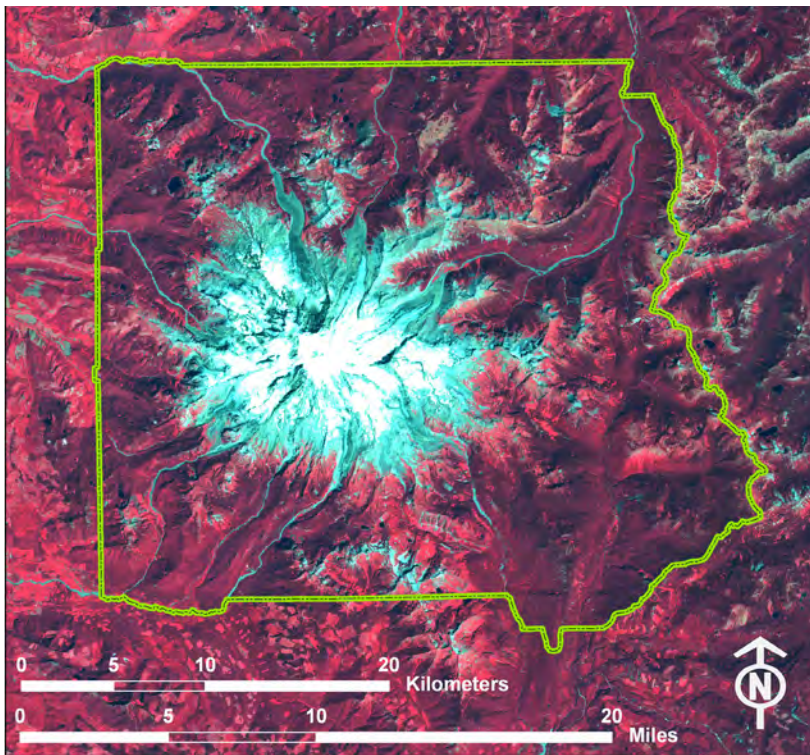

2005 "false-color" Landsat image composite for Mount Rainier National Park. The combination of these bands is often used to identify vegetated areas that now appear bright red due to high refeflectance of leaves in the near infrared wavelength region. Different shades of red represent different vegetation types and conditions.

Monitoring Strategy

Added together, the NCCN parks surpass a total area of more than 2,800 square miles, covering significantly more ground than the entire state of Delaware. Attempting to physically monitor even a portion of the network's landscape by foot—or even by airplane—is neither feasible nor practical. With modern satellite imaging technology, however, the task is now not only possible, but efficient and economical. The landscape dynamics monitoring program uses the well-established Landsat satellite system to detect significant landscape changes by comparing yearly sets of images and other information. The Landsat program, managed by NASA and the U.S. Geological Survey, launched its first imaging satellite in 1972. Today, with its fifth and seventh satellites still operating, the program provides invaluable data for a multitude of applications in agriculture, forestry, water use, and natural resources monitoring. Landsat cameras work by scanning the earth and translating everything on the landscape into images made up of colored pixels, with each pixel representing 900 square meters (30 by 30 m) of the Earth's surface. A Landsat image of a national park consists of millions of these pixels.

All of Earth's surfaces reflect various wavelengths of light from the sun, and Landsat separates these wavelengths into seven visible and infrared "bands" of the electromagnetic spectrum, recording a number value for each of the seven bands at each pixel. Each individual band can be particularly useful in the identification of different surface conditions (see below). From year to year, computational comparisons between these bands—or combinations of bands—reveal the changing nature of the Earth's surface.
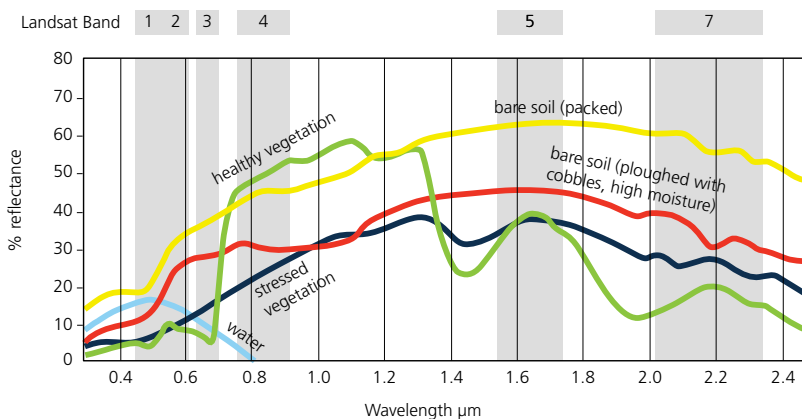
Simplified spectral reflectance curves for various landcover types. Different surfaces transmit or reflect different amounts of energy in different wavelengths along the electromagnetic spectrum. Landsat bands are designed to capture areas of the spectrum that would allow for easy identification of these cover types based on their behavior in various bands.

Imagine looking down on a forest of several thousand trees. On a Landsat true-color image, this forest would appear as an area of hundreds of green-shaded pixels. Because of variations in tree species, density, and understory throughout this forest, the pixels would vary slightly in shade from one to the next.

Next, imagine that a large landslide sweeps through the middle of this forest, leaving a gash of rock and bare soil where trees once stood. On a new Landsat image, the pixels would now register as shades of brown (or white, indicating bare rock) wherever the landslide removed the trees. Comparing the new image with the old, a significant change has clearly occurred, and considering the context and appearance of the new image, a landslide would be the most apparent cause. Years later, as new vegetation reclaims the soil, the pixels would slowly transition back toward shades of green.

Because Landsat records reflectance values in both visible and infrared wavelengths of the electromagnetic spectrum, it can detect more subtle changes in vegetation cover better than the human eye could. An insect infestation that reduces a tree's vigor instead of killing it might not be visible to the naked eye, but can be tracked by Landsat.

Researchers are able to track the changes in pixels' reflectance values on an annual basis thanks to a computer program called LandTrendr, which was developed by a group of scientists at Oregon State University (see top photo, opposite page). The program graphs the reflectance values of individual Landsat pixels through time. Returning to the example of the landslide in the forest, a graph of a pixel's reflectance values over time would register a sudden spike when the landslide occurred. Over decades, as vegetation grows over the soil and reclaims the area, the graph would gradually return to its original reflectance values. Because each type of landscape change creates a distinct pattern in these graphs, NPS researchers can use the pattern to help them identify the agent of the disturbance.

"We know a lot from these disturbance trajectories," said NPS ecologist Dr. Catharine Copass Thompson, lead researcher on the landscape dynamics monitoring program. "If the disturbance has a certain type of geometry and it's a slow change, we know it's probably caused by insects. If it has a short duration, it's intense and long and skinny, and it goes from a high elevation to a low elevation, it's probably an avalanche. Following logical rules about the landscape context in which changes occur in combination with the spectral information, we can identify what has happened."
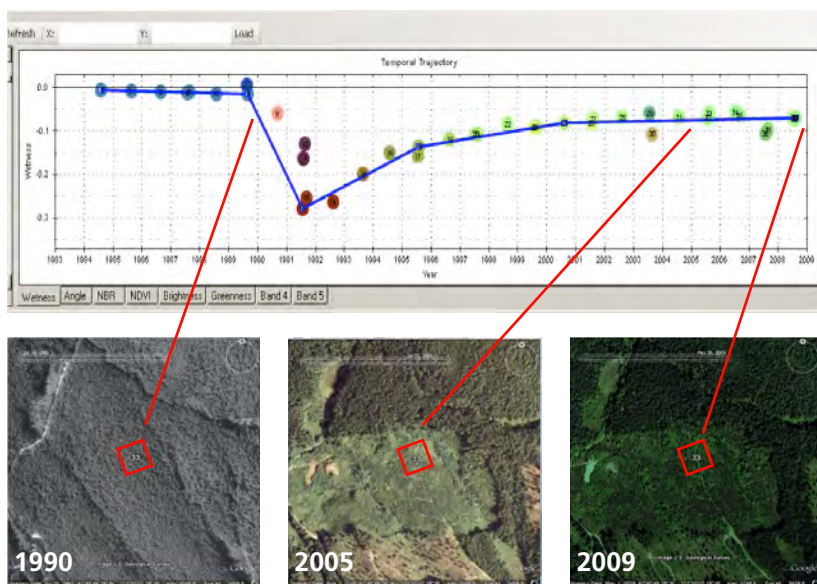
Spectral trajectory of an individual pixel through time. Bluish-green circles indicate high values of wetness and greenness in vegetation, corresponding to mature conifer forest. Red circles indicate removal of vegetation, characterized in reduction of wetness and greenness and increase in brightness. Over time, as vegetation recovers, the pixel's greenness and wetness increase, eventually returning to the original spectral condition.

Data Collection

Because data from the landscape dynamics monitoring program come entirely from yearly satellite image comparisons, the program is unique among NCCN Vital Sign monitoring programs in that it involves no outdoor data collection from field technicians. Instead, the primary tools used by Thompson and GIS specialist Natalya Antonova—the program's two NPS personnel—are computers and telephones.

Once each year's images undergo LandTrendr statistical analysis to detect all pixels that changed from the previous year, data are processed in a GIS to combine pixels into individual disturbance events based on their size. Each year, Landsat detects countless small variations in the landscape, but many small changes simply represent "noise" that must be filtered out. Instead, events are only tracked if they consist of a minimum of 9 adjoining pixels, or the equivalent of at least 8,000 square meters (2 acres). (see example of a large event on the next page)

Once individual disturbance events are delineated, researchers apply a statistical model to the data to label the event with a disturbance type, such as fire, windthrow, clearcut, or riparian disturbance. The statistical model com-
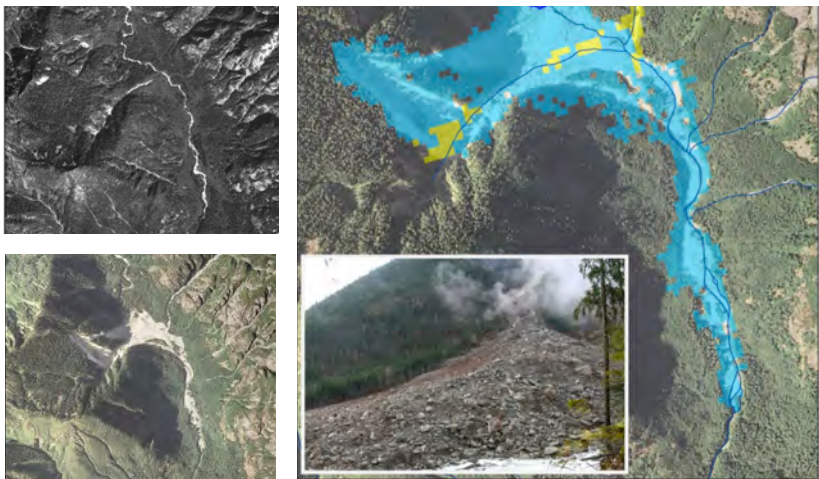
2003 Goodell Creek Landslide at North Cascades National Park. The left side images show 1-meter resolution aerial photos taken before (1998) and after (2006) the landslide.The right side image shows the landslide as detected and mapped by the LandTrendr algorithm. Areas in yellow outline riparian disturbances that took place a year prior to the landslide. Areas in light blue show the extent of the landlide.
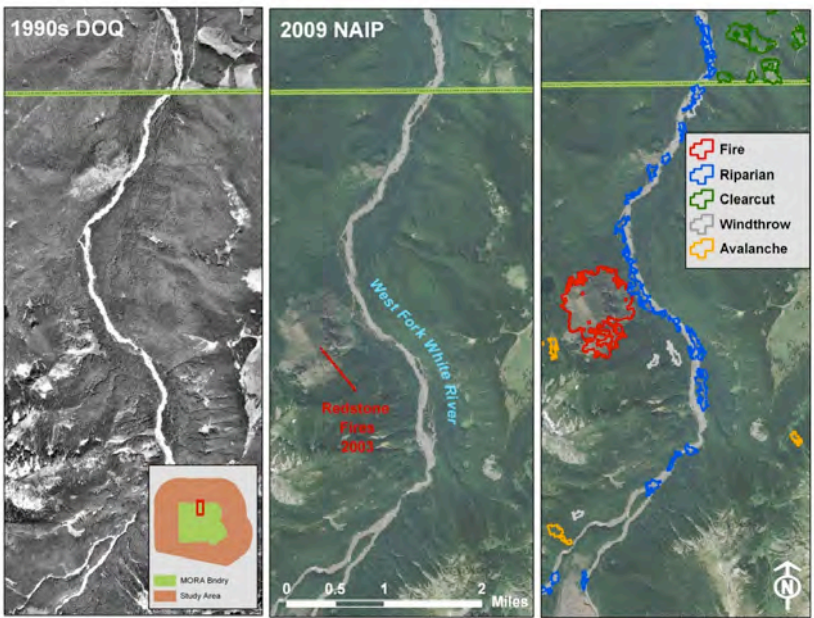
Several types of disturbances at Mount Rainier National Park. The 1990 black and white photo shows conditions prior to disturbance. The 2009 true-color aerial photo shows post-disturbance conditions. On the right, the 2009 photo is overlaid with LandTrendr processing and agent labeling results from 1985 to 2008, outlining and highlighting changes that might not have been easily detected by looking at the photos themselves.

bines information about the event's shape, size, and location on the landscape with the information about the event's duration and magnitude from the LandTrendr algorithm. For example, a square-shaped disturbance event outside the park boundary that changes from dark green to a bright color might indicate a clearcut. A disturbance event with a more irregular shape that is located on a valley wall and shows some decrease in greenness might indicate a windthrow event where vegetation was only partially removed. Over the years, NPS scientists can use this information to create maps that show an aggregate of all the park's changes during a certain timeframe (see bottom three photos on opposite page).

The program will include a "ground-truthing" component, consisting of verifying a random subset of disturbance events using high-resolution aerial photography. In addition, opportunistic sampling in the field will be accomplished by park field crews working on maintenance or other resource inventory and monitoring projects.

Once disturbance events are identified, labeled, and verified, the researchers will synthesize the information into a series of graphs comparing the type and extent of disturbances throughout the NCCN. These graphs compare each year according to factors such as the total area disturbed, the number of each type of disturbance event, and the amount of landscape change outside the park compared to inside. For the first time, the NPS will know about various landscape disturbances that occur in the inaccessible sections of the parks. For example, instead of knowing only that a storm caused windthrow damage in a certain region of the park, researchers will be able to identify the exact locations and estimate the total surface area impacted.

Current Trends

The NCCN's landscape dynamics monitoring program officially began in the spring of 2011 at the network's three largest parks: Olympic, North Cascades, and Mount Rainier. After amassing several years' worth of data, the program will allow researchers to identify links between Pacific Northwest weather patterns and the frequency and timing of certain disturbance events, potentially leading to more accurate predictions of those events. Over decades, the program will also allow the NPS to track all event-related landscape changes.

Researchers predict that global climate change may cause some disturbances, such as fires and floods, to increase in frequency and intensity (University of Washington Climate Impacts Group). Evidence to verify or refute these predictions will come directly from this monitoring program and similar projects around the region. With this study, the NCCN parks will serve as frontiers for some of the most expansive and detailed natural resource monitoring in the Pacific Northwest.

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